CHAPTER 5

Basics of Time

Introduction

In this chapter you will be introduced to the basics of time. You may be asking yourself what part time plays in the practice of navigation. You may be surprised to find out how important time actually is. For example, when we use time to mark the exact second of celestial observation an error of a few seconds could result in a fix error of many miles from the correct fix position.

Objectives

The material in this chapter will enable the student to:

- Define the terms *apparent* and *mean* solar time.
- Match the following kinds of time with their definitions:
  a. Greenwich mean time (GMT)
  b. Universal time (UT)
  c. Local mean time (LMT)
  d. Zone time (ZT)
  e. Zone description (ZD)
- State why standard time zones are used and how they are measured.
- Calculate ZD from ship's longitude.
- State the procedures for adjusting a ship's time and date at sea.
- Convert ZT to GMT.
- Convert GMT to ZT.
- Identify the equivalent values for arc and time.
- Convert time to arc and arc to time manually.
- Convert arc to time using *The Nautical Almanac.*

Major Topics

Apparent Time and Mean Solar Time

Background Information

In this section of the course, we will discuss time in more abstract terms. We will look at how time is measured, some basic terms and definitions associated with time, time zones and time zone conversions, and how we convert time to arc and arc to time.

The instrument for measuring time is a timepiece. Earth itself may be considered as our celestial timepiece. Each complete rotation of Earth on its axis provides a unit of time that we know as a day. Time is important to you because of its relationship to longitude. As a Quartermaster, you will have to understand this relationship to do your job.

The Solar Day

The two types of time we will discuss here are:

1. Apparent solar time.
2. Mean solar time.

You probably already know that the motion of the Sun and the stars around Earth is only apparent--an illusion created by the rotation of the Earth itself. Solar time is based upon the rotation of the Earth with respect to the Sun.

The solar day is equal to one rotation of Earth relative to the Sun.

Apparent Time

Apparent solar time is measured upon the basis of the apparent motion of the real Sun (the one you see rise and set every day). This is why we use the term *apparent* when we measure time using the apparent Sun. When the Sun is directly over our local meridian (directly overhead), we say that it is noon, local apparent time. When it is directly over the meridian that is 180° (on the opposite side of Earth) away from ours, it is midnight local apparent time.

If Earth remained stationary in space, all the days reckoned by apparent time would be of the same length. But Earth travels in an elliptical orbit around the Sun, and its speed relative to the Sun varies with its position in its orbit. Consequently, the time required for a complete revolution of Earth on its axis, although constant as applied to points on Earth, varies regarding Earth relative to the Sun. The length of a day measured by a complete revolution of Earth with regard to the Sun, also varies. For this reason it is impractical for man-made timepieces to keep apparent time; another solution had to be figured to account for these unequal lengths of time.

Apparent and Mean Solar Time, Continued

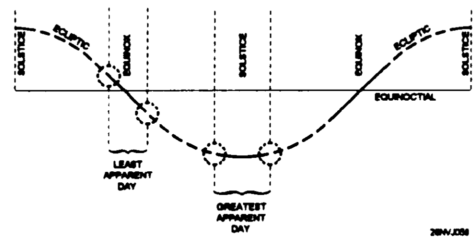


Figure 5-l Difference in the time of an apparent day.

Mean Solar Time

To remedy the situation created by apparent solar time, mean solar time was introduced. Mean solar time is based on a fictional Sun that is considered to move at a constant rate of 360° in 24 hours along the celestial meridian. One mean day is 24 hours in length, each hour consisting of 60 minutes, and each minute consisting of 60 seconds.

Mean solar time and apparent solar time are nearly equal, but mean solar time is the time used in everyday life (fig. 5-1). It is the time kept by our ship's chronometers and clocks, even our own wristwatch. It is also the time used in various almanacs that we use for tabulating the positions of celestial bodies.

Equation of Time

The difference between the apparent day and the mean day is never more than a minute. This difference is cumulative and amounts to as much as a quarter-hour at certain times of the year (fig. 5-2). ***The difference between mean and apparent time at any instant is called the equation of time.***

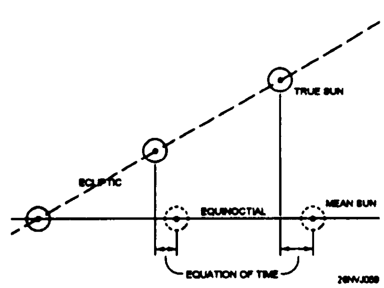


Figure 5-2. Difference of mean time and solar time.

Definition of Terms

GMT

Greenwich mean time (GMT) is the basis or origin of longitude measurement. It is mean solar time measured with reference to the 0° meridian of longitude located at Greenwich, England. GMT is of prime importance to you because much of the time referenced in almanacs relates to GMT.

UT

When we discussed mean solar time we said that it was based on a fictional Sun that is considered to move at a constant rate of 360° in 24 hours along the celestial meridian. This solved the problem of unequal day length, but even with mean time there are slight variations. The most precise time yet developed by man is kept by atomic "clocks," which operate using cesium beam oscillators. This steady, internationally adjusted time is called Coordinated Universal Time (UTC). For our purposes, it is the same as GMT and is the time signal broadcast as radio time signals.

LMT

Local mean time is mean solar time measured with reference to your meridian; that is, the meridian where you are located.

ZT

Zone time is the time you use to set your watch and clocks. Zone time uses the standard (central) meridians of the various time zones as reference meridians.

ZD

The zone description of a time zone is the adjustment to be applied to that time zone to determine GMT.

Discussion

Although most of the above terms may be new to you, they will all make sense when we cover the rest of the material in this chapter. In carrying out the daily routines you will often be required to convert time zones and work with time calculations. After a bit of practice, the procedures contained in this chapter will become second nature. In fact, in most cases you will learn to quickly do time calculation in your head.

Let’s move on to how time is broken down into standard meridians (zones) and then how that relates to longitude.

Standard Time Zones

Introduction

You can understand how a general foul-up would result if all people set their watch on their own LMT. As you know, local mean time (LMT) always differs in different longitudes. In a large city, for example, a difference of about 9 seconds (9s) LMT occurs between one end of the city and the other end. If you set your watch on your LMT you would have to change it every time you went a few blocks on a street running east and west.

To eliminate this difficulty, standard time zones have been established within which all clocks are set to the same time, zone time (ZT). A difference of 1 hour (lh) takes place between one time zone and the next. Because 1h is 15°, you can see that each time zone comprises 15° of longitude. Thus resulting in 24 time zones, and 25 time zone designations.

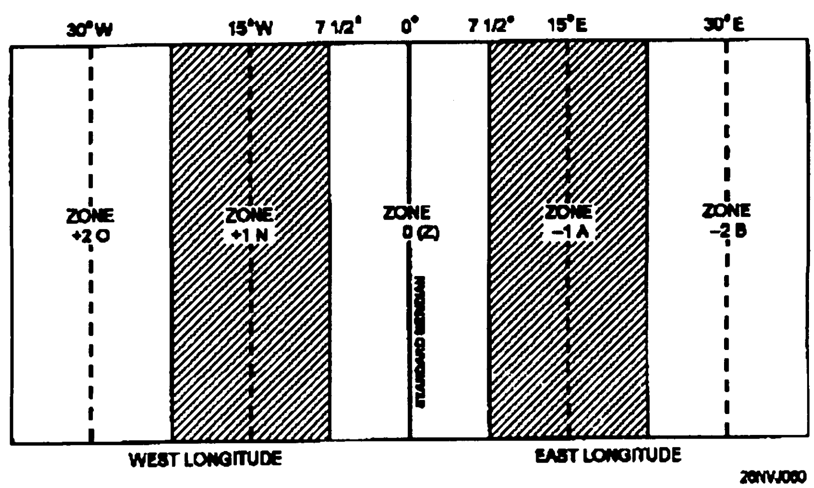


Figure 5-3. Time zones.

Local mean time along each standard time meridian is zone time for the entire time zone. Look at figure 5-3. In zone 0, time is exactly the same within 7 1/2° either side of the standard meridian. Zone time in navigation is abbreviated ZT.

Daylight savings time is simple zone time set ahead 1 hour to extend the time of daylight.

The Relationship between Time and Longitude

Background Information

Ordinarily, we use mean solar time, which is measured by the motion of the mean Sun around the Earth. Let's suppose your ship is on longitude 60°W. When the Sun is on your longitude or meridian, it is noon. As the Sun continues to move west and crosses over longitude 61°W, it is noon there and the time on your meridian is later. In fact it is the time equivalent of 1° later. But you can't measure 1° on your watch; you must convert this 1° of arc to units of time.

To have a standard reference point, every celestial observation is timed according to the time at the Greenwich meridian. Usually this is determined by means of the chronometer which is set to GMT. To clarify the relationship between time and arc, let's consider a situation in which you know your longitude exactly at noon, and you want to find out the time in Greenwich.

Arc to Time

When the Sun is on a particular meridian, it is noon at that meridian. In other words, when the Sun is on the Greenwich meridian (0°), it is noon by Greenwich time. To make the problem easier, let's say you're in 90°W longitude. It's noon where you are, so the Sun must also be in 90°W longitude. So, since leaving Greenwich, the Sun has traveled through 90° of arc. Because it was 1200 (noon) Greenwich time when the Sun was at 0°, the time at Greenwich now must be 1200 plus the time required for the Sun to travel through 90° of arc.

The following information provides all the elements of a problem for converting arc to time. If you know that it takes 24 hours for the Sun to travel 360° or one complete revolution, it should be easy to find how long it takes it to go 90°. If the Sun goes 360° in 24 hours, it must go 15° in 1 hour. If it goes 15° in 1 hour, it must go 1° in 4 minutes. Then, to go 90°, it takes 90 x 4 minutes, or 360 minutes, which is the same as 6 hours. Six hours ago it was 1200 Greenwich time; therefore, the time at Greenwich now must be 1800. You actually have converted 90° of arc to 6 hours of time. In doing so, you discovered the basic relationship between arc and time. This relationship is stated as 15° of longitude (arc) equals 1 hour of time.

Your problem could be converting time to arc--the reverse of the one we worked out. Tables for converting either way *are* in *The Nautical Almanac* and in *Bowditch*, but if you acquire the following easy methods of converting, you won't have to refer to publications. First, you must memorize the values for arc and time.

ArctoTime Relationship

Use this table to learn the relationship between arc and time.

EQUIVALENTS OF ARC AND TIME	
Time to Arc	Arc to Time
24h = 360° lh = 15° lm = 15' 1s = 15"	360° = 24h 1° = 4m 1' = 4s

Converting Time to Arc

The following is a step by step example of the time to arc conversion process:

Step	Action	Example: Convert 14h 21m 39s units of time to arc
1.	Multiply the hours by 15 to obtain degrees.	14h × 15 = 210°
2.	Divide the minutes by 4 to obtain degrees; multiply the remainder by 15 to obtain minutes of arc.	21m ÷ 4 = 5° 15' (remainder lm × 15 = 15')
3.	Divide the seconds of time by 4 to obtain minutes and minutes of arc, or multiply the remainder by 15 to obtain seconds of arc.	39s ÷ 4 = 9' 45" (remainder 3s × 15 = 45")
4.	Add degrees, minutes, and seconds.	Answer: 210° 24' 45"

Continued on next page

Converting Arc to Time

The following table shows how to convert arc to time.

Step	Action	Example: Convert 215°24' 45" of arc to time.
1.	Divide the degrees by 15 to obtain hours, and multiply the remainder by 4 to obtain minutes of time.	215° ÷ 15 = 14h20m
2.	Divide the minutes of arc by 15 to obtain minutes of time, and multiply the remainder by 4 to obtain seconds of time.	24' ÷ 15 = lm36s (remainder 5° × 4 =20m)
3.	Divide the seconds of arc by 15 to obtain seconds of time.	45" ÷ 15 = 3s (remainder 9' × 4 = 36s)
4.	Add hours, minutes, and seconds.	Answer: 14h21m39s

Finding ZD

To calculate the ZD for a given position, follow the steps as shown below.

Step	Action
1.	Divide the longitude of the position by 15°.
2.	If the remainder is less than 7°30', the whole number quotient from step 1 equals the ZD.
3.	If the remainder is more than 7°30', the ZD is one more than the whole number of the quotient.

Example 1: 135° W ÷ 15 = 9 The longitude is west, so the ZD = +9.

Example 2: 062° W ÷ 15 = 4 with a remainder of 2. The remainder is LESS THAN 7°30" and the longitude is west, so the ZD = +4.

How to Convert Arc to Time Using *The Nautical Almanac*

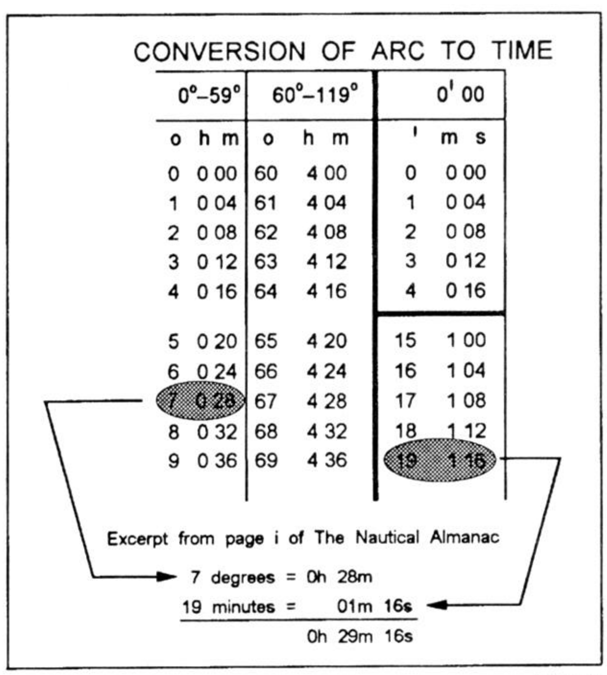
Example

In the following example, you will learn how to convert arc to time using a table from *The Nautical Almanac.*

<u>Example</u>: Suppose your DR longitude is 142° 41' W, and ZT is 06h 21m 09s. Divide 142° 41' by 15, and you find that your ZD is +10. This means that your standard meridian must be 150°W. To simplify the arithmetic, express the 150°W longitude as 149° 60' W. The values are equal and subtraction is made easier this way.

Standard time meridian	149°60' W
Longitude your meridian	<u>142°41'</u>
Difference of Longitude	7°19'

Using the conversion of arc to time excerpt shown in figure 5-4, change 7° 19' to time, and you get 00h 29m 16s. This means that LMT at your meridian differs from ZT by 00h 29m 16s.



CONVERSION OF ARC TO TIME

0°–59°		60°–119°		0' 00	
°	h m	°	h m	'	m s
0	0 00	60	4 00	0	0 00
1	0 04	61	4 04	1	0 04
2	0 08	62	4 08	2	0 08
3	0 12	63	4 12	3	0 12
4	0 16	64	4 16	4	0 16
5	0 20	65	4 20	15	1 00
6	0 24	66	4 24	16	1 04
7	0 28	67	4 28	17	1 08
8	0 32	68	4 32	18	1 12
9	0 36	69	4 36	19	1 16

Figure 5-4. Excerpt from *The Nautical Almanac.*

How to Convert Time

Converting ZT to GMT

In our previous discussion of ZD, we said that each standard meridian (those meridians exactly divisible by 15) is 1 hour apart and that each of these standard meridians is identified by a number and letter sign. To convert ZT to GMT, or GMT to ZT, the first thing you must determine is the correct ZD. ZT differs from GMT by the ZD.

Rule: When you convert ZT to GMT, you must apply the ZD to your ZT using the proper sign, minus (-) if you are in east longitude, plus (+) if in west longitude.

Example 1: Assume that you are in longitude 105°E, ZT is 16h 23m 14s, and you want to find GMT.

Step	Action
1.	Find your ZD. 105 ÷ 15 = 7.
2.	Determine the sign of the correction. You are in east longitude, so the sign is negative.
3.	Apply the correction. Your ZD is -7. The minus sign means that you subtract ZD from ZT to obtain GMT. ZT 16h 23m 14s ZD -7 GMT 09h 23m 14s

Example 2: Assume you are in longitude 75°W, ZT is 07h 13m 57s, and you want to find GMT.

Step	Action
1.	Find your ZD. 75 ÷ 15 = 5. Therefore, you are in zone 5.
2.	Determine the sign of the correction. You are in west longitude, so the sign is positive.
3.	Apply the correction. Your ZD is +5, so add the correction to ZT to obtain GMT. ZT 7h 13m 57s +5 GMT 12h 13m 57s

Converting GMT to ZT

When you convert GMT to ZT, you must apply the ZD to your ZT using the opposite sign; plus (+) if in east longitude, minus (-) if in west longitude.

Example 1: Assume that you are in longitude 156° 58'E, GMT is Olh 00m 00s on 01 July. You want to find ZT.

Step	Action
1.	Find your ZD. Divide 156° 58' by 15 and you get 10.
2.	Determine the sign of the correction. You are in east longitude, so the sign is minus (-10).
3.	Apply the correction using the opposite GMT 01h 00m 00s ZD +10 ZT 11h 00m 00s

Example 2: Assume that you are in longitude 145° 00' W and GMT is 16h 00m 00s on 30 December. You want to find ZT.

Step	Action
1.	Find your ZD. Divide 145° 00' by 15 and you get 10.
2.	Determine the sign of the correction. You are in west longitude so the sign is plus (+10).
3.	Since you are going from GMT to ZT, apply the correction using the opposite sign (-10). GMT 16h 00m 00s ZD -10 ZT 06h 00m 00s

Time and Date for Ships at Sea

Ship's Clocks

As your ship travels east or west at sea and passes between one time zone and the next, it is convenient for you (and everyone else on board) to adjust the ship's clocks to the time zone where you are actually located. As you pass from one time zone to the next, ZT changes by 1 hour. But do you advance the clocks 1 hour, or do you set them back 1 hour? The rule is:

If you are traveling towards the **west,** the new ZT will be 1 hour earlier; therefore, you must set the ship's clocks ***back*** 1 hour.

If you are traveling towards the **east,** ZT will be 1 hour later; therefore, you must set the ship's clocks ***ahead*** 1 hour.

The ship's navigator or quartermaster should notify the commanding officer when these changes become necessary. Do NOT, in any case, ever advance or retard the ship's chronometer.

International Date Line

So far we've been talking about advancing or retarding clocks to account for time zone changes as we travel over the oceans. Suppose your ship is in the Pacific Ocean traveling west. As you continue to travel west, you are setting your clocks back 1 hour each time you enter a new time zone. Eventually, you will lose 24 hours in a circumnavigation of the Earth. Because of this, a method for adjusting for the day lost (or gained when you were traveling east) is necessary and is accomplished by the International Date Line, which follows the 180th meridian. The rule for changing date when crossing the International Date Line is:

When traveling **east** and crossing the International Date Line, you compensate by ***retarding*** the date 1 day.

When traveling west and crossing the International Date Line, you compensate by ***advancing*** the date 1 day.

<u>**Note:**</u> The date change is in the opposite direction to the hour changes you made as you passed into each new time zone. This date change is made by every vessel that crosses the International Date Line, regardless of the length of the voyage.

The International Date Line is used as a convenience just like time zones. Changing the date should take place at a convenient time that is least disruptive to the operation of your ship.

Timepieces

Introduction

The quartz chronometer is the main source for keeping shipboard time (fig. 5-5). A chronometer is like any watch except that it keeps time to a higher degree of accuracy. For detailed information on the components and upkeep of shipboard chronometers, refer to *NSTM,* chapter 252.

Error and Rate

Even a chronometer cannot keep exact time indefinitely. Sooner or later the chronometer time gradually begins to draw away from GMT (UTC). The difference between chronometer time and GMT, at any instant, is called ***chronometer error.*** Error direction is identified with a sign or letter (+ or F = Fast) or (- or S = Slow) to indicate that the chronometer is either fast or slow in relation to the correct GMT.

Chronometer rate, on the other hand, is the amount the instrument gains or loses in a specified time.

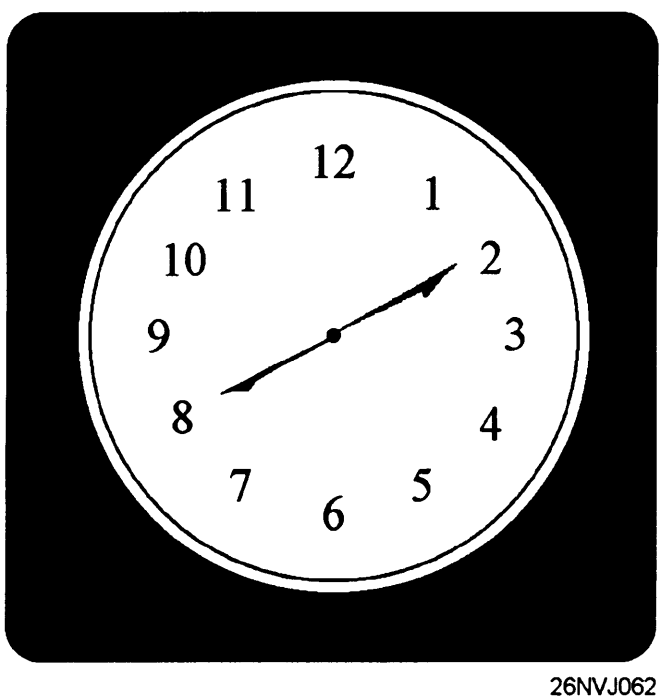


Figure 5-5. Quartz chronometer.

Chronometer Error

Introduction

Inasmuch as chronometers are never reset aboard ship, an accumulated error may become quite large. Such an error is unimportant, though, if an accurate record is kept of the error. The most accurate check on the chronometer and other timepieces is by comparing the radio time signal broadcast by radio station WWV and other stations listed in *Radio Navigational Aids* (Pub No. 117) with the chronometer time.

Time Ticks

Since 1 January 1973, the broadcast time signals (UTC) have differed from GMT by amounts up to ±0.7s. The difference arises because the times given in the navigational tables depend on the variable rate of rotation of the Earth, while the broadcast time signals are now based on an atomic time scale. Step adjustments of exactly 1 second are made to the time signals as required (normally at 24th on December 31 and June 30) so that the difference between the time signals and GMT may not exceed 0.9s. For those who require GMT to an accuracy better than 1s, a correction (DUT) is coded into the transmitted time signal. GMT accurate to 0.1s is obtained by applying DUT to the transmitted time signal; that is,

GMT = UTC + DUT

Naval radio stations transmit time signals (on seven different frequencies) for the 5 minutes immediately preceding certain hours GMT. The DUT correction is given in Morse code in the final 9-second pause prior to the long dash.

Each second in the time signal is marked by the beginning of a dash; the end of the dash has no significance. Beginning at 5 minutes before the hour, every second is transmitted except the 51st second of the 1 st minute, 52nd second of the 2nd minute, 53rd second of the 3rd minute, 54th second of the 4th minute, 29th second of each minute, the last 4 seconds. of each of the first 4 minutes, and the last 9 seconds of the last minute. The hour signal after the 0-second break (59m 60s) consists of a longer dash than the others. For clarity, the system of dashes are shown graphically in the accompanying table on the next page.

Minute	50	51	Second 52	53	54	55	56	57	58	59	60
			-	-	-	-			-		
55	-			-	-	-			-		
56	-	-	-		-	-			-		
57	-	-	-	-		-			-		
58	-										
59	-	(+DUT)									

Other Time Tick Available

All other time signal transmissions, for example, WWV (Ft. Collins, Colo.), WWVH (Honolulu), CHU (Ottawa, Can.), are broadcast on 2.5, 5, 10, 15, 20, and 25 megahertz and consist of dashes at the beginning of each second (commencing with the zero second of each minute). DUT is coded into the first 16 seconds by doubling of the dashes in seconds. 1 to 8 for +0.1s to +0.8s, and in seconds 9 to 16 for -0.1s to -0.8s. For example: If DUT = +0.4s, the dashes for seconds 1, 2, 3, 4 would be double; if DUT = -0.6s, the dashes for seconds 9. 10, 11, 12, 13, 14 would be double.

The upcoming time is announced during the interruption of the audio frequency. The exact time is taken the instant the audio frequency is resumed. An example of the voice announcement might be: "THIS IS RADIO STATION WWV. At the tone, the time will be 8 hours, 50 minutes, coordinated universal time."

Documenting Chronometer Error

Navigational Timepiece Rate Book

Information concerning each chronometer (error, successive daily rate, and average daily rate) must be recorded in the *Navigational Timepiece Rate Book*, NAVSEA 4270. (See fig. 5-6.) Each page of NAVSEA 4270 can accommodate the records of a maximum of three chronometers for 1 month.

How to Check and Record Error

Use the following table to check and record chronometer error. You will need pencil, paper, and a comparing stopwatch handy.

Step	Action
1.	Obtain a time tick signal from the communications center.
2.	Determine from the time tick the next minute that will be sounded; write this value down. When the signal is sounded, start the comparing watch.
3.	At the exact moment the comparing watch marks on the minute, note the exact time for chronometer 1. Write down the time for chronometer 1.
4.	Compare the two time values and determine the difference of time. It is always preferable to change the larger time value to ease addition or subtraction. In our example, the comparing watch time is the larger value and equals 1 lh 15m 00s. This converts to 11h 14m 60s. **Example:** Comparing watch llh 14m 60s GMT Chrono time - llh 14m 43s GMT Chrono error 0h 00m17s
5.	Record results in the Timepiece Rate Book, compare the results with the previous day and compute the difference, assign a - value if the chronometer is slower; assign a + value if the chronometer is faster.
6.	Repeat steps l-5 for the remaining chronometers, replacing chronometer 1 with the chronometer you are comparing.

New Time Source

At the time of publishing of this TRAMAN, the use of GPS time as the single source reference for setting ships time has not been approved. However, the use of GPS time signals may be approved in the near future. Check with your Type Commander Staff Navigator for guidance on this matter.

How to Determine Daily Rates

DATE	A					B					C					OBSERVATION	
YEAR 19 84	MAKE HAMILTON, TYPE SC, SERIAL NO. 4327					MAKE HAMILTON, TYPE SC, SERIAL NO. 1278					MAKE HAMILTON, TYPE GCW, SERIAL NO. 843						
MONTH July	ERROR RELATIVE TO G.C.T. + - FAST, − - SLOW			SUCCESSIVE DAILY RATES		ERROR RELATIVE TO G.C.T. + - FAST, − - SLOW			SUCCESSIVE DAILY RATES		ERROR RELATIVE TO G.C.T. + - FAST, − - SLOW			SUCCESSIVE DAILY RATES		LOCAL TIME TO NEAREST MINUTE	
DAY	±	MIN.	SECONDS	±	SECONDS	±	MIN.	SECONDS	±	SECONDS	±	MIN.	SECONDS	±	SECONDS	TIME	INITIALS
1	+	1	4.5		.	−	2	4.6		.	+	12	42.4		.	1155	
2	+	1	6.0	+	1.5	−	2	3.8	+	0.8	+	12	40.0	−	2.4	1205	
3	+	1	7.5	+	1.5	−	2	3.0	+	0.8	+	12	37.5	−	2.5	1140	
4	+	1	9.0	+	1.5	−	2	2.2	+	0.8	+	12	35.1	−	2.4	1135	
5	+	1	10.6	+	1.6	−	2	1.4	+	0.8	+	12	32.7	−	2.4	1120	
6	+	1	12.1	+	1.5	−	2	0.5	+	0.9	+	12	30.2	−	2.5	1200	

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Figure 5-6. Excerpt from the Timepiece Rate Book.

Average Daily Rate (ADR)

Example: a chronometer whose rate is +1.5 seconds will gain 1.5 seconds every 24 hours. Chronometer rate is usually expressed as seconds and tenths of seconds per day and is labeled *gaining* or *losing.* Chronometer rate is determined by comparing errors obtained several days apart and dividing the difference by the number of days between readings.

Date	Correct GMT (UTC)	Chrono. time	Error	Chrono. rate
17 July	11h 30m 00s	11h 32m 00s	02m 00s	
18 July	11h 30m 00s	11h 32m 01s	02m 01s	+1s

Average daily rate (ADR) is found by using the formula:

$$\text{ADR} = \frac{\text{(error on last day observed) - (error on first day observed)}}{\text{(date of last observation) - (date of first observation)}}$$

ADR formula for a 3 l-day month. A navigator desiring to determine the chronometer rate compares the chronometer directly with the Washington, D.C., (NSS) 1200 radio time signal on different days. On the first day the chronometer reads fast by 9 minutes 3.0 seconds and on the last day it reads fast by 9 minutes 53.5 seconds. ADR is found as follows:

$$\text{ADR} = \frac{\text{(F) 09m 53.5s - (F) 09m 3.0s}}{(31) - (1)} \quad \frac{\text{50.5s diff}}{\text{30 days}} = \underline{\qquad\qquad} = \text{1.68s/gaining}$$

No attempt should be made to determine chronometer error closer than l/2 (0.5) second. Average daily rates, therefore, are somewhat a more accurate measurement of the chronometer's performance than are the daily checks because, in the former method, any daily observational errors are averaged out.

Timing Celestial Observations

Background

The importance of obtaining the exact GMT (UTC) of every celestial observation was mentioned earlier. Obviously, it would be impractical if every time you took a sight on the bridge wing, you had to dash into the charthouse and look at the chronometer. Every observation, consequently, is timed the instant it is made, either by a stopwatch or by a comparing watch.

Techniques

There are several methods available for timing observations. In this text we will cover the preferred method only. The preferred method consists of one person taking observations and another person marking the exact time of the observation. The person marking the time will need to use a comparing watch set to GMT from a time tick or set to chronometer time.

The stopwatch can be started exactly on some convenient minute or hour of the chronometer. If its rate is known to be small, there is no necessity for working out any chronometer minus watch (C-W) computation, provided the interval during which observations are taken is short. For a single observation, the stopwatch can be stopped (or, reversing the procedure, the watch may be started) when the sight is taken, but seldom is only one observation made. For this reason, the stopwatch must usually be read like any other watch.

A comparing watch can be set to the chronometer time and can be used to keep time if its rate is also small. Some navigators, though, prefer to keep their watches on zone time; hence, observation time must be computed. It doesn’t matter whether computation is made before or after the observation. It is essential to have the interval as short as possible between time of sight and time of computation. Otherwise, enough time may elapse for the watch to gain or lose a sufficient amount to cause an error. For better accuracy and to avoid careless errors, it’s a good idea to make C-W computations both before and after a round of sights.

Timing Celestial Observations, Continued

Techniques

The C-W computation is watch time (WT) to the half-second subtracted from chronometer time (CT). If WT is greater, 12 hours must be added to CT. The C-W is never greater than 12 hours because both watch and chronometer are graduated only to 12. Now that you know the value of C-W, it is necessary only to add this value to the WT of any observation to find the correct CT, then apply chronometer error (CE), and you have the GMT (UTC) of the observation.

Examples

To work an example, assume that you have a chronometer whose error (CE) is -7m 4s; in other words, it is 7m 4s behind GMT (UTC). Your watch is set to ZT and reads 5h 26m 42s when the chronometer reads 10h 19m 00s. First, find the C-W. It's WT subtracted from CT.

CT	10h	19m	00s
WT	5h	76m	42s
C-W	4h	52m	18s

You step out on the bridge with our sextant and watch, and sight on Sirius at WT 5h 34m 21s, date 15 October, longitude 101°34.2'E. What should be the GMT (UTC) of this sight? Applying the formula
CT = WT + C-W, we find:

WT	5h	34m	21s
CE		7m	04s
GMT	10h	33m	43s

Now, let's consider the date 15 October at 101°34.2'E. Is it the same day at Greenwich? Let's see. The ZT is 5h 34m 21s. The ZD is -7. Subtract ZD from ZT to get GMT (UTC). You can't subtract 7 from 5, but 5h on 15 October is the same as 29th on 14 October, and 7 from 29 is 22. Therefore, 1 Oh 33m 43s is not a.m. on 15 October, but p.m. on 14 October. From this computation, it follows that GMT (UTC) is 22h 33m 43s on 14 October.

In problems like these, you must check the date carefully every time to avoid a 12-hour error such as the one we encountered just now.